Available online at www.sciencedirect.com
ScienceDirect
Journal of Forensic and Legal Medicine 15 (2008) 382–387
JOURNAL OF FORENSIC AND LEGAL MEDICINE
www.elsevier.com/jflm

Original Communication

CT data-based navigation for post-mortem biopsy – A feasibility study

Emin Aghayev MD (Research Assistant) [a,b,*], Lars C. Ebert (PhD Student) [c], Andreas Christe MD (Radiologist) [a,d], Christian Jackowski MD (Resident at the Institute of Forensic Medicine) [a], Tobias Rudolph (PhD Student) [c], Jens Kowal (Group Head – Smart Surgical Instrumentation) [c], Peter Vock MD (Chief of the Department of Diagnostic Radiology) [d], Michael J. Thali MD (Chief of the Institute of Forensic Medicine) [a]

[a] *Institute of Forensic Medicine, University of Bern, Buehlstrasse 20, CH-3012 Bern, Switzerland*
[b] *Institute for Evaluative Research in Orthopaedic Surgery, MEM Research Centre, University of Bern, Stauffacherstrasse 78, CH-3014 Bern, Switzerland*
[c] *Institute for Surgical Technology and Biomechanics, MEM Research Centre, University of Bern, Stauffacherstrasse 78, CH-3014 Bern, Switzerland*
[d] *Institute of Diagnostic Radiology, University Hospital, CH-3010 Bern, Switzerland*

Received 18 September 2007; received in revised form 14 January 2008; accepted 8 February 2008
Available online 11 April 2008

Abstract

Introduction: Recent advances in medical imaging have brought post-mortem minimally invasive computed tomography (CT) guided percutaneous biopsy to public attention.
Aims: The goal of the following study was to facilitate and automate post-mortem biopsy, to suppress radiation exposure to the investigator, as may occur when tissue sampling under computer tomographic guidance, and to minimize the number of needle insertion attempts for each target for a single puncture.
Methods and materials: Clinically approved and post-mortem tested ACN-III biopsy core needles (14 gauge × 160 mm) with an automatic pistol device (Bard Magnum, Medical Device Technologies, Denmark) were used for probe sampling. The needles were navigated in gelatine/peas phantom, ex vivo porcine model and subsequently in two human bodies using a navigation system (MEM centre/ISTB Medical Application Framework, Marvin, Bern, Switzerland) with guidance frame and a CT (Emotion 6, Siemens, Germany).
Results: Biopsy of all peas could be performed within a single attempt. The average distance between the inserted needle tip and the pea centre was 1.4 mm ($n = 10$; SD 0.065 mm; range 0–2.3 mm).

The targets in the porcine liver were also accurately punctured. The average of the distance between the needle tip and the target was 0.5 mm (range 0–1 mm).

Biopsies of brain, heart, lung, liver, pancreas, spleen, and kidney were performed on human corpses. For each target the biopsy needle was only inserted once. The examination of one body with sampling of tissue probes at the above-mentioned locations took approximately 45 min.
Conclusions: Post-mortem navigated biopsy can reliably provide tissue samples from different body locations. Since the continuous update of positional data of the body and the biopsy needle is performed using optical tracking, no control CT images verifying the positional data are necessary and no radiation exposure to the investigator need be taken into account. Furthermore, the number of needle insertions for each target can be minimized to a single one with the *ex vivo* proven adequate accuracy and, in contrast to conventional CT guided biopsy, the insertion angle may be oblique.

Navigation for minimally invasive tissue sampling is a useful addition to post-mortem CT guided biopsy.

* Corresponding author. Address: Institute for Evaluative Research in Orthopaedic Surgery, MEM Research Centre, University of Bern, Stauffacherstrasse 78, CH-3014 Bern, Switzerland. Tel.: +41 31 631 59 30; fax: +41 31 631 59 31.
E-mail address: emin.aghayev@memcenter.unibe.ch (E. Aghayev).

1752-928X/$ - see front matter © 2008 Elsevier Ltd and FFLM. All rights reserved.
doi:10.1016/j.jflm.2008.02.007

Keywords: Virtopsy; Forensic radiology; Post-mortem biopsy; Computed tomography; Navigated biopsy; Needle autopsy

1. Introduction

Currently, in forensic medicine, cross-sectional imaging is being recognised as a non-invasive examination approach[1–3], but neither computed tomography (CT) nor magnetic resonance imaging are able to provide tissue information at the cellular level in a non-invasive manner. DNA, bacteriological, algological and other specific tissue analyses are impossible using radiology.

Recent advances in medical imaging have brought post-mortem minimally invasive image-guided percutaneous biopsy to public attention.[1] This approach allows for minimally invasive tissue sampling and provides forensically relevant tissue information at the microscopic level.[1] In the study, post-mortem biopsy was manually performed under CT guidance.[1]

The main goal of the Virtopsy project is the development of minimally invasive techniques for post-mortem examinations of the body. It is imaginable that all currently studied techniques, such as post-mortem biopsy, angiography, diagnostic imaging and surface scanning, will be sometime combined in an "all in one" machine such as the recently described Virtobot®,[2] which might be then able to sample a tissue probe with the push of one button. According to this goal, the step-by-step automation of the techniques, among other – biopsy, is outstanding.

The goal of the following study was to facilitate and automate post-mortem biopsy procedures, to decrease the risk of exposure of the investigator to ionizing radiation, and to minimize the number of needle insertion attempts to a single puncture while maintaining the accuracy of needle placement in the target.

2. Material and methods

Clinically approved and post-mortem tested ACN-III biopsy core needles (14 gauge × 160 mm) with an automatic pistol device (Bard Magnum, Medical Device Technologies, Denmark) were used for sampling the probes.[1] The needles were navigated in a gelatine/peas phantom, in an *ex vivo* porcine model and subsequently in two human corpses using a navigation system (MEM Centre/ISTB Medical Application Framework, Bern, Switzerland) with a guidance frame and a CT.

2.1. CT

CT scanning of the gelatine phantom with peas, of the *ex vivo* porcine model and the human bodies was carried out on a 6-row scanner (Emotion 6, Siemens, Germany) using a collimation of 6 × 0.5 mm (slice thickness 0.63 mm, reconstruction kernel B30s).

2.2. Navigation system

A navigation system (MEM Centre/ISTB Medical application platform, Bern, Switzerland) including an optical tracking system (Polaris, Northern Digital Inc., Ontario, Canada) for continuous update of positional data of the body and the biopsy needle was used.[4,5] The navigation system tracks the position of active (light emitting diode) and passive (infra-red reflectors) optical markers. Four marker shields, each consisting of four optical markers, were used to track positions of tools and rigid objects. A marker shield was mounted on the biopsy pistol (passive) (Fig. 1a), a pointer (passive), the needle guide (active) and the CT table (active). Each marker shield spans a local coordinate system in which the spatial position of the biopsy pistol or the CT slice stack are defined. This definition is done by using pivoting algorithms (pointers), calibration blocks (biopsy needle) or paired point matching (CT volume dataset).[4] Within the setup of the navigation system each tool was calibrated once.

2.3. General workflow for navigated biopsy

The navigation procedure consists of six steps:

First, at least four radiologically visible multimodality markers (IZI Medical, Baltimore, USA) are placed onto the object undergoing biopsy to allow for paired point matching (1) (Fig. 2a). Subsequently, a CT scan of the object is performed (2) and the CT volume dataset is uploaded to the navigation system (3). The dataset is registered to the CT table fixed coordinate system by using paired point- and surface matching techniques (4).[4,5] The next step is the definition of the biopsy target in the dataset (5), followed by insertion of the needle and biopsy (6).

The insertion of the needle can either be manually performed or using a needle guide. The needle guide consists of a frame with a 60 cm long arm with three ball joints and a needle guider at the end of the arm (Fig. 1a). The frame can be mounted to the side fasteners of the CT table. Using the three ball joints the arm with the needle guide can be easily positioned in a user-defined direction within the radius of approximately 60 cm.

2.4. Preliminary studies

The following three studies were performed to test the accuracy of the post-mortem navigated biopsy.

2.4.1. Study 1

A phantom of concentrated gelatine containing ten equally sized peas (mean diameter 5.5 mm; range 5–6 mm) was prepared. The biopsy was performed manually without the needle guide (steps 1–6).

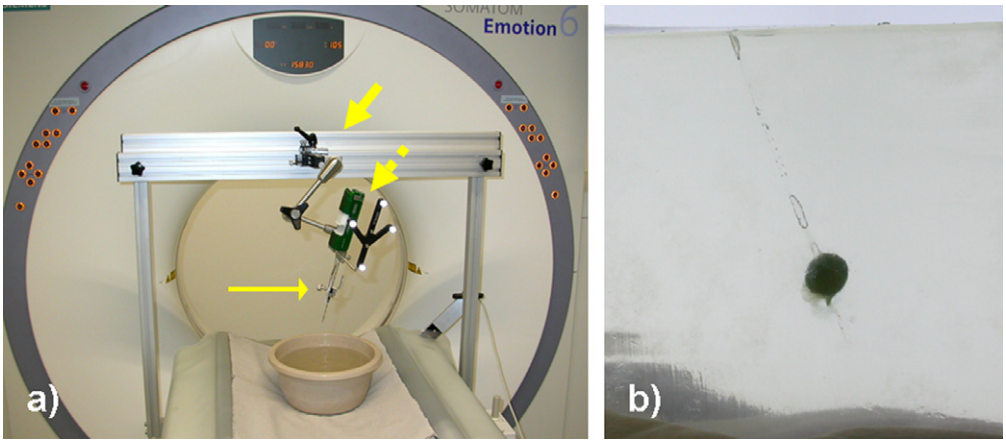

Fig. 1. Study 2: (a) The biopsy of peas in a gelatine phantom using a needle guide (thick arrow) is shown on the image. The needle guide consists of a frame (thick arrow) that is mounted to the side fasteners of the CT table, a 60 cm long arm with three ball joints and a needle guider at the end of the arm (thin arrow). The pistol device with the biopsy needle passes through the needle guider (thin arrow); (b) A slice of the gelatine phantom shows a trace of the biopsy needle and a punctured pea.

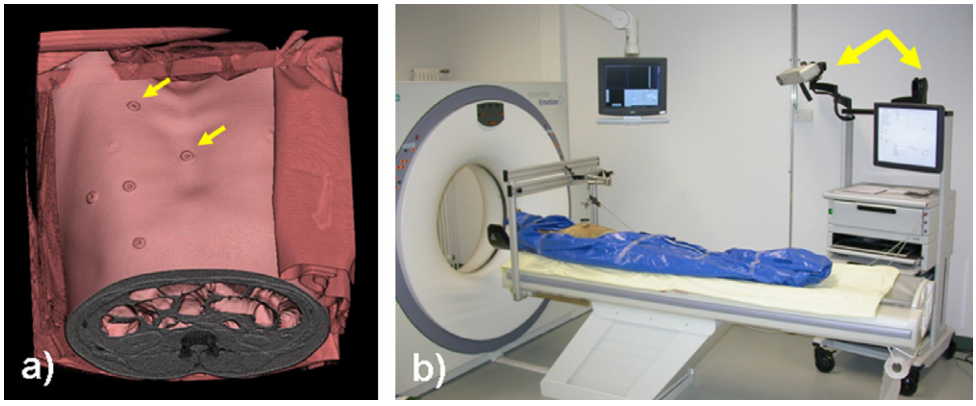

Fig. 2. (a) The image shows 3D volume rendering reconstruction of the CT data of the thorax of the human case 1. The radiologically visible multimodality markers are placed on the right thorax (arrows). (b) The set up of the CT data-based biopsy of the human case 2 using the navigation system (double arrow) and the needle guide mounted to the CT table.

2.4.2. Study 2

The same steps as in the previous study were applied on a similar phantom, with the exception that before step 6 – insertion of the needle and biopsy – the needle guide was firstly brought into the correct position and the insertion of the needle was performed through the needle guide (Fig. 2).

2.4.3. Study 3

This study with a porcine liver was carried out to test the biopsy in biological tissue and to thereby check for possibly different needle-tissue behaviour in a biologic organ as compared with the gelatine phantom.

Using a conventional syringe, traces of a contrast medium were injected into the depth of the organ in three different points to provide three radiologically visible targets. Within the last step of the general workflow, biopsy of the contrasted targets in the liver was manually performed.

In all these studies, the examined object was scanned following the biopsy and the calculation of the distance between the needle tip and the centre of a target was performed on the angulated CT images.

2.4.4. Human corpses

Application of the biopsy method to human bodies was approved by the local ethical committee. One cadaver donated to research from the local anatomical institute and another one admitted to our institute for forensic autopsy underwent navigated biopsy. The steps for the navigated biopsy were the same as in the general workflow followed by selection of targets in the brain, heart, lung, liver, pancreas, spleen and kidney. The additional guide frame (as in the preliminary study 2) was used. At least one specimen (range 1–3) from each location was sampled in both cases.

The approaches for different tissues were the same as in the previously reported study.[1] Removed tissue samples were fixed in phosphate-buffered 4% paraformaldehyde, routinely processed and stained for histology. The stained sections were evaluated by a board-certified pathologist.

Following the biopsy procedure, the body from the anatomical institute was returned without autopsy. The body admitted to our forensic institute routinely proceeded for a conventional autopsy.

3. Results

3.1. Study 1

A probe from a pea was achieved in a single attempt in seven out of ten peas. For the remaining three peas a second attempt was necessary. The calculated averaged distance between the needle tip and the centre of pea was 1.8 mm ($n = 7$; SD 0.029; range 1.4–2.3 mm).

3.2. Study 2

Biopsies of all the peas were performed with a single attempt (Fig. 1b). The calculated averaged distance between the needle tip and the centre of pea was 1.4 mm ($n = 10$; SD 0.061 mm; range 0–2.2 mm).

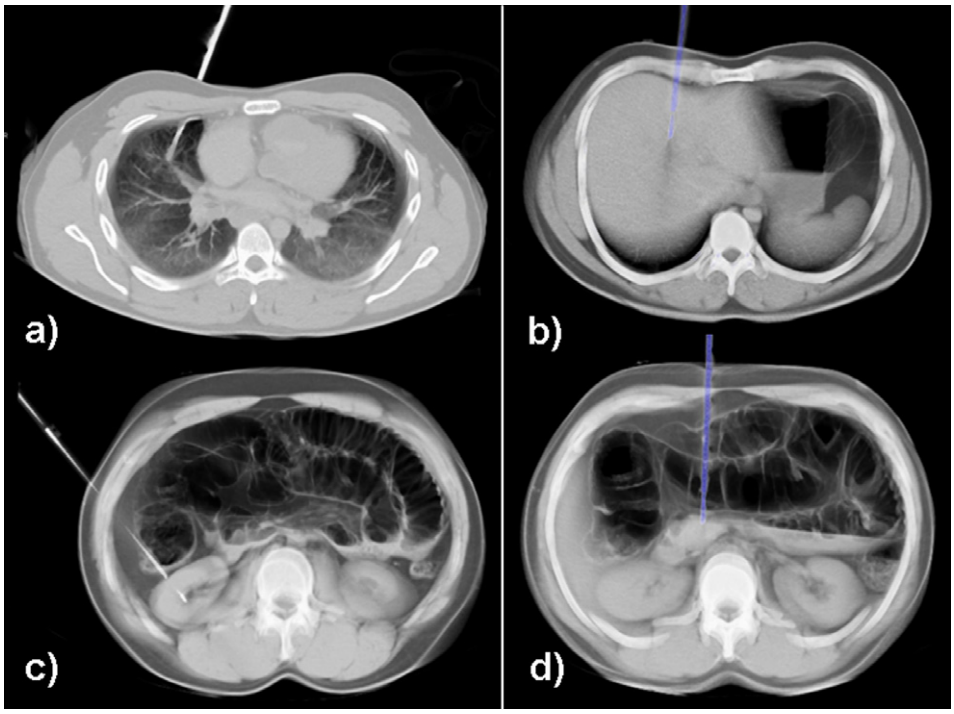

Fig. 3. 3D reconstructions of the needle inserted to the right lung (a), liver (b), kidney (c) and pancreas (d) using a wide window with a centre between usual bone and lung windows. In the images (b) and (d), the biopsy needle is coloured for better visualization.

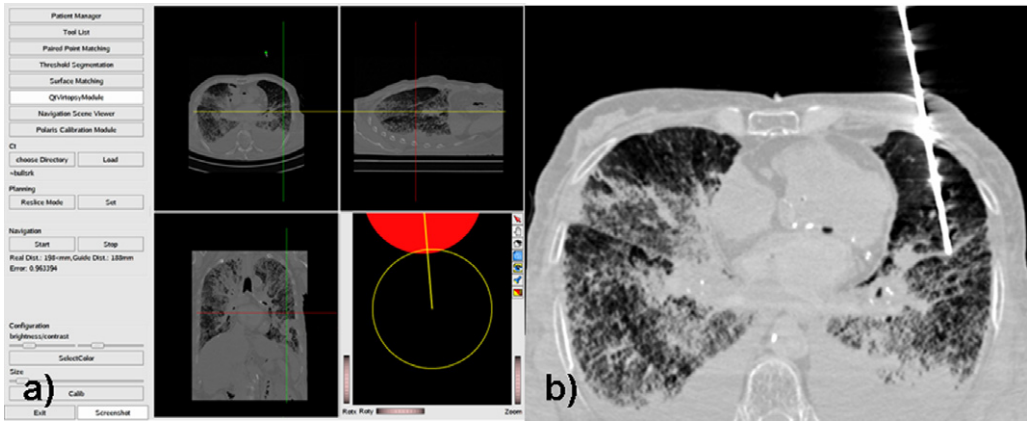

Fig. 4. Selecting a target and the biopsy of the lung in the human case 2: (a) Screenshot of the navigation system demonstrates planning of the target in the left lung. Note the two circular targets in the lower right corner; their overlap changes the colour gradually to green and indicates a correctly directed needle; (b) Angulated CT image shows needle inserted into the left lung before the biopsy.

3.3. Study 3

Biopsies of all three targets in the liver, which were approximately 2.5 mm in size (range 2–3 mm), were accurately achieved. The average distance between the needle tip and the aimed centre of the target was 0.5 mm ($n = 3$; range 0–1 mm).

3.4. Human corpses

Biopsies of the brain, heart, lung, liver, pancreas, spleen and kidney were accurately performed (Fig. 3). For each target the biopsy needle was inserted only once. The biopsy of the brain was performed as a separate biopsy procedure with a repetition of all steps.

The preparation of a biopsy procedure including steps 1–4, until a target was selected and punctured, took approximately 15 min. The selecting of a target and its biopsy required less than 2 min for each target (Fig. 4). Thus, in a body, sampling of tissue probes from the above mentioned locations took approximately 50 min. Tissue samples of adequate quality with a mean width of 1.6 mm (range 1.2–1.9 mm) and a mean length of 15 mm (range 5–20 mm) were obtained from all locations.

4. Discussion

Post-mortem minimally invasive biopsy is a requisite for definitive diagnosis within the concept of image-guided post-mortem virtual autopsy. Additionally to the diagnostic abilities of post-mortem medical imaging, this approach provides forensically relevant tissue information at a microscopic level using a minimally invasive approach. Its practicality has been shown in a previous study, where tissue sampling was performed under CT fluoroscopy[1], which is well known in clinical medicine. Although this procedure may look simple and easy, there is a challenge in precisely and consistently aiming and delivering the needle. Misplacement of biopsy needles are usually associated with longer examination times since they require extra CT images or control scans verifying the position of the needle after corrective replacement. Additional CT fluoroscopy may lead to increased radiation exposure to the investigator – as it is known from the clinical literature. Misplacements also include overdriving the needle, which may destroy surrounding tissue.

The goal of the present study was to facilitate and automate post-mortem biopsy procedures, to make them less hazardous for the investigator and to confine the number of needle insertion attempts for a target to a single puncture, while retaining the accuracy of needle placement in the target.

A navigation system for guiding the biopsy needle was constructed. The accuracy of its navigation for manual biopsy was tested on a gelatine phantom in study 1. In this study, needle bending was the major limitation for an accurate puncture of the peas. Therefore, for the second study an additional guidance frame/needle guide was constructed. This frame with the needle guider allowed the prevention of most of the needle bending outside the phantom. The accuracy of the biopsy in the second study was considerably better with the guidance frame.

The study with the porcine liver was performed to ascertain possible accuracy differences between biopsy in biological tissue and in gelatine. Puncturing of contrasted targets in a porcine liver, however, exhibited good accuracy of the navigated biopsy, comparable to the studies with peas.

Following the accuracy tests, the navigated biopsy was applied to human corpses. Biopsies of the brain, heart, lung, liver, pancreas, spleen and kidney were performed. Using the guidance frame, the biopsy of each target required only one needle insertion as desired for the described study.

The lowest accuracy was documented in study 1 when performing a manual biopsy. The manual biopsy is faster in comparison with the frame-guided biopsy because the frame does not have to be mounted and positioned. Such a biopsy technique may be reasonable when precision is less essential.

We separated the biopsy procedure of the brain from the biopsies of the other organs performing CT scans of the head and trunk as two procedures to avoid possible movements of the head in relation to the trunk and, thereby, a lower accuracy. However, this would be unnecessary if the rigor mortis of the body is definitive or if the head is fixed to the CT table.

Using the presented navigation system, only one CT scan of the body part undergoing biopsy is necessary. This scan is performed from beyond the radiation area prior to the biopsy procedure. The continuous update of positional data of the body and the biopsy needle during the tissue sampling is provided by the optical tracking of the navigation system. Thus, control images of the needle position are unnecessary and the risk of exposure to ionizing radiation of the investigator is thereby decreased to a minimum.

Optical navigation is a recognized tool in clinical biopsy as well as in orthopaedic, maxilo-facial or neuro-surgery for guidance. The major limitation of its use for navigated clinical biopsy is patient movements, which need not be taken into account when using post-mortem navigated biopsy.

Using conventional CT guided biopsy, it is necessary to insert the biopsy needle in the axial plane to be able to observe the whole needle on axial CT control images in order to estimate its direction. Since the positional data of the biopsy needle and the body is continuously updated using optical tracking, the navigated biopsy allows for an oblique insertion of the needle. This provides more free space for performing a biopsy, avoiding bones or injury to important tissues en-route. This can be very helpful in the biopsy of lung tissue, which is widely overlapped by ribs. A hole in the skull for the brain biopsy may also be placed at any site and used for biopsy access to multiple locations.[1]

One reasonably skilled medical investigator using the assistance of a second person, e.g. of the CT technician who is performing the CT scan, can deal with the user-friendly navigation system performing such a biopsy.

Our studies suggest that the primary cause of needle placement error is needle bending. Using the guidance frame it is possible to overcome most of the needle bending outside the body. The guidance frame stabilises the biopsy needle during insertion. The observer-dependant swinging of the needle with the pistol device is thereby minimised. Any bending of the needle that still exists might be reduced applying thicker and stronger needles.

Although in the preliminary study good results in the biopsy of the porcine liver were achieved, we did not obtain samples from defined organ locations of focal pathology but just obtained normal organ histology. Furthermore we did not simulate and test tissue inhomogeneities in a penetrated body which we suppose may cause needle placement errors.

The examination time of a body with tissue sampling from the above mentioned locations is a current limitation. The direct registration of the radiological dataset of the body on the CT table might save up to two thirds of the preparation time. This is the theme of ongoing work. Implementation of a robotic arm for biopsy might also considerably automate, facilitate and speed up the minimally invasive biopsy procedure. The use of similar biopsy techniques with a robotic arm for selected applications in clinical patients has already been reported.[6–8] Finally, we did not compare the results of histological examination of biopsy specimens with the specimens sampled at autopsy since we had only two human corpses, only one of which underwent autopsy. Further multi-case studies on this issue are certainly desirable.

In summary, post-mortem navigated biopsy can reliably provide tissue samples from different locations of the body. Since the continuous update of positional data of the body and the biopsy needle is performed using optical tracking, no control CT images verifying the positional data are necessary and thus no radiation exposure to the investigator arises. The number of needle insertions can be minimized to a single one with the proven adequate accuracy and, in contrast to conventional CT guided biopsy, the insertion angle may be oblique.

In the foregoing, we believe that we have been able to demonstrate that navigation for minimally invasive tissue sampling is a useful addition to post-mortem CT guided biopsy.

Acknowledgments

We are grateful to Bettina Nicolet-Zeller (Institute of Forensic Medicine, University of Bern) for the excellent help in treating the sampled specimens.

References

1. Aghayev E, Thali MJ, Sonnenschein M, Jackowski C, Dirnhofer R, Vock P. Post-mortem tissue sampling using computed tomography guidance. *Forensic Sci Int* 2007;**166**:199–203.
2. Dirnhofer R, Jackowski C, Vock P, Potter K, Thali MJ. Virtopsy: Minimal invasive, image guided virtual autopsy utilizing optical surface – and radiological cross sectional scanning: traditional autopsy turning into high-tech forensic investigation. *Radiographics* 2006;**26**:1305–33.
3. Thali MJ, Yen K, Schweitzer W, et al. Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI)-a feasibility study. *J Forensic Sci* 2003;**48**:386–403.
4. Veldpaus FE, Woltring HJ, Dortmans LJ. A least-squares algorithm for the equiform transformation from spatial marker co-ordinates. *J Biomech* 1988;**21**:45–54.
5. Bachler R, Bunke H, Nolte LP. Restricted surface matching–numerical optimization and technical evaluation. *Comput Aided Surg* 2001;**6**:143–52.
6. Fichtinger G, DeWeese TL, Patriciu A, et al. System for robotically assisted prostate biopsy and therapy with intraoperative CT guidance. *Acad Radiol* 2002;**9**:60–74.
7. Masamune K, Fichtinger G, Patriciu A, et al. System for robotically assisted percutaneous procedures with computed tomography guidance. *Comput Aided Surg* 2001;**6**:370–83.
8. Cadeddu JA, Bzostek A, Schreiner S, et al. A robotic system for percutaneous renal access. *J Urol* 1997;**158**:1589–93.